

An Analysis of Health Risk and Potential Elimination Strategies of Anti-nutritional Factors in Cereals and Legume

ABSTRACT

The nutrients contained in cereals and legumes play pivotal roles as building blocks of living organisms. The cereals are rich in carbohydrates, dietary fibers, vitamins, and minerals, whereas the legumes are good source of protein and amino acids with other vitamins and minerals. But these cereals and legumes contain a few groups of anti-nutritional factors (ANFs) that minimize the quality of nutrition by nature or other indirect mechanisms which is detrimental to health. There are some direct and indirect techniques to downgrade the activity of these adverse components by different mechanisms. A good number of research have been conducted to unscrew the harmful effects of anti-nutritional factors and the present review discussed the downsides of cereals and legumes used in animal feed and human consumption along with the means of subsidence to increase the quality of nutritional values.

Keywords: Nutrition, Cereals, Legumes, ANF, Food, Feed

1. INTRODUCTION

For the survival of living organisms and to maintain the processes of growth and healing of damaged tissues, nutrition is the precondition of health (Mattila *et. al.*, 2018). Cereals and legumes play an important role in human nutrition and animal feeding. Cereal grains such as rice, wheat, and maize provide ample amounts of carbohydrates, proteins, and vitamins with dietary fiber which are very important for bodily function (Nadeem *et. al.*, 2010). For vegetable protein sources legumes such as soybean, rapeseed, mustard seed, lentil, chickpea, cranberry beans, etc. are widely cultivated throughout the world. Though cereals are deficient in lysine but main source of calories in the South Asian diet contains complex vitamin B with sulfur-containing amino acids like methionine and cysteine which are limited in legumes (Concon 1975 and Gulzar 2011). With vitamins and calories, cereals are also rich in minerals such as zinc and iron (Temba *et. al.*, 2016). Tharanathan and Mahadevamma (2003) legumes are one of the highest crops containing protein, carbohydrates, dietary fiber, and minerals. Legumes are an excellent source of protein and essential amino acids like lysine. Legume consumption has a pivotal role in the reduction of blood pressure (Polak *et. al.*, 2015). Soybean is one of the high-ranking legumes for feed and food production and a major source of vegetable protein and edible oil (Gu C. *et. al.*, 2010). For containing relatively high protein and suitable amino acids, it has a universal acceptability in animal feed. Mustard seed or rapeseed is another crop from the Leguminosae family which is cultivated for edible oil and protein meals. The amino acid profile of protein in rapeseed is well balanced and the essential amino acids are far better than cereals (Thanaceelaan V., 2013). In tropical and sub-tropical climates peanut or ground nut is a seed crop that comes under the leguminous family [61-63]. It is consumed as a component of formulated or processed foods, roasted nut, and edible oil extraction and the ground nut seeds are good sources of essential minerals e.g., calcium, phosphorus, magnesium, and zinc with vitamin B1 (Stalker 1997 and FAO 2002). Faba bean, lupin, rapeseed, flaxseed, oil hemp, buckwheat, and quinoa are among the most promising protein-rich plants of legumes, oil crops, and pseudo cereals may offer good alternatives to soybean and contribute to the environmental and economic sustainability of local agricultural production (Mattila *et. al.*, 2018). Cereals and legumes are staple food crops all over the world and have an important role in animal feed but contain some anti-nutritional factors. According to Samtiya *et. al.*, (2020) grains and legumes not only contain high amounts of macro and micronutrients but also some antinutritional factors that combine with nutrients to reduce nutrient bioavailability. In the case of animal feeding antinutritional components are found in traditional or non-traditional roughages, cereals, legumes, shrubs, etc. in green as well as dry-matter basis (Ramachandra *et. al.*,

2019). According to (Makkar H., 1993) these harmful substances also called anti-quality factors can be divided into four categories: (I) affecting protein utilization and depressing digestion (protease inhibitors, tannins, saponins, lectins, etc.), (II) metal ion scavengers (oxalates, phytates, gossypol pigments, glucosinolates), (III) antivitamin, (IV) mycotoxins, mimosine, cyanogens, nitrates, alkaloids, photosensitizing agents, isoflavones, etc.). Cereals and legumes are very rich in minerals but for the presence of antinutritional factors, the bioavailability of these minerals interferes. Cereals mostly contain phytates, and enzyme inhibitors but some cereals like sorghum and millet contain a large number of polyphenols and tannins (Salunkhe et al., 1990). Among cereals maize is one of the most important crops and contains some antinutritional factors. It has been reported by Okafor UI et. al., (2018) that most of the maize varieties contain tannins and phytic acids which make different nutrients unavailable to the human or animal body. Like other cereals, legumes are also rich in sources of different antinutritional factors that affect the nutritional value, utilization, and digestibility of protein. Soybean meal is a major source of plant protein, and it contains many kinds of anti-nutritional factors such as trypsin inhibitor, lectin, α -amylase inhibiting factor, goitrin, soybean antigen, etc. (Liener IE, 1994). The antinutritional factors present in soybean meals not only affect the digestibility and nutritional value but also cause digestive and metabolic diseases with reduced performance traits (Sun, Z.W. and Qin, G.X, 2005). After soybean meal mustard seed or rapeseed meals are one of the main protein sources for animals. Despite the significant amounts of highly valued nutrients the utilization and marketing of rapeseed meal is very limited due to the presence of glucosinolates and others (G. Mejicanos et. al., 2016). Though glucosinolates are not harmful themselves directly, their hydrolytic products such as goitrogenic and potential hepatotoxic compounds e.g., isothiocyanates thiocyanates are very harmful to both animals and humans (T. Chun and B. Brian, 2004). The antinutritional factors present in food or feed ingredients are highly deleterious for health but there are several ways to reduce their activities. Some of the antinutritional factors heat stable or heat labile, so, different traditional and up-to-date ingredients or food processing techniques such as soaking, fermentation, heating, cooking, puffing, extrusion, etc. can reduce antinutritional factors in food or feed ingredients. According to Handa et. al., (2017) traditional processing techniques not only reduce the antinutritional factors but also increase protein digestibility and improve the biological value of cereal crops. In recent years several reviews have been done about antinutritional factors in food and feed and the aim of this review is to assess updated scientific information for potential health benefits and adverse effects of antinutritional factors with reduction strategies.

2. ANTINUTRITIONAL FACTORS AND ANIMAL NUTRITION

Cereals and legumes are used as sources of different types of nutrients for animal feeding. Along with nutritional sources, there are several types of anti-nutritional factors present in these ingredients. These factors include phytates or phytic acid, protease inhibitors, lectins, saponins, tannins, gossypol, amylase inhibitors, glucosinolates, antivitamin factors, metal binding agents, goitrogens, etc. They tend to antagonize nutrition, either by causing toxicity or secondary nutritional deficiency by chelation of important nutrients that are necessary for animal nutrition.

2.1. PHYTIC ACID OR PHYTATE

A six-fold dihydrogen phosphate ester of inositol naturally found in the plant kingdom and phytates mixed cation salt of phytic acids are generally known as myo-inositol-1,2, 3,4,5,6-hexakis dihydrogen phosphate, which is present in foods at various levels ranging from 0.1 to 6.0% (Gupta et. al., 2015). In the structure of phytic acid, there are 6 phosphate groups with 12 hydrogens and at physiological pH, phosphates are partially ionized. The negatively charged sites bind potassium and magnesium and in these cases, phytates contain 50-80% of the total phosphorus of the seed (Lott et. al., 2000). Phytic acids affect the bioavailability of minerals and hinder the activity of enzymes that are essential for protein degradation in the small intestine and stomach (Chan et.al., 2007; Kies et. al., 2006). At low pH, phytic acids bind with protein complex and reduce the stability of trypsin which affects the protein digestibility (Caldwell, 1992). According to Francis et. al., (2001), common feedstuffs such as soybean and rapeseed meal contain 10-15 and 50-75gm phytate per kg whereas Hossain and Jauncey (1993) reported that 5-10gm phytic acids per kg diet caused slow growth in fish. Phytate or phytic acid content can be decreased by several techniques. Soaking and cooking can greatly reduce phytic content and during germination, phytic acid is degraded by some native enzyme of seeds (Larsson and Sandberg 1992; Vadivel and Biesalski 2012). Milling is one procedure that separates

the bran or aleurone layer from the seed where phytates are present, but this may remove some minerals (Gupta *et. al.* 2015).

2.2. ENZYME INHIBITORS

Enzyme inhibitors are a set of substances in size of small and large molecules of proteins that bind with enzymes and reduce their activity (Srinivasan B, 2022). Proteinase enzymes play various roles in enhancing the nutritional and functional properties of protein molecules (Salas *et. al.*, 2018) Protease inhibitors, α -amylase inhibitors, lipase inhibitors, and lectins are found in legumes which could lead to low bioavailability of minerals with poor absorption and digestibility (Bajpai *et. al.*, 2005). Most of the legumes contain protease inhibitors which reduce the proteolytic activity in the gastrointestinal system. According to Nørgaard *et al.* (2019), the presence of protease inhibitors in diets can interfere with the activity of protease enzymes within GIT. Commonly, most proteinase inhibitors observed in soybeans belong to either the Kunitz inhibitor family or Bowman-Birk inhibitors (Liu 1997). These inhibitors may bind one trypsin and one chymotrypsin at one time or at the same time. The Kunitz inhibitors only bind with trypsin, but the Bowman-Birk inhibitors inhibit both trypsin and chymotrypsin (R. Ramachandra *et. al.*, 2019). According to the study of Liener. I. (1980) In the intestine, firstly inhibitors form a stable complex and stimulate secretion of pancreatico-cholecystokinin (PZ-CCK) from the gut cell wall which stimulates pancreatic tissue to secrete trypsin as well as stimulates the gall bladder to empty its content into the intestine. In young chickens, developed hypertrophy of the pancreas has been seen due to protease enzyme. Trypsin inhibitors interfere with the availability of Methionine and reduce the apparent digestibility of protein and lipids (R. Ramachandra, 2019; Berg-lea *et. al.*, 1989). Trypsin inhibitors can be affected by temperature, duration of heating, moisture level, and particle size. It has been reported by Patterson *et. al.*, (2017) that boiling or cooking highly improved the nutritional value of foods by reducing their antinutritional (e.g., tannins and trypsin inhibitors) contents.

Amylase inhibitors affect the activity of α -amylase enzymes in the gastrointestinal tract of humans and animals. The function of the α -amylase enzyme is breaking down carbohydrates such as polysaccharides into oligosaccharides. The inhibitors present in cereals and legumes affect the activity of enzymes and delay carbohydrate digestion by increasing the absorption time. Bhutkar and Bhise (2012) have reported that the increasing time of carbohydrate digestion slows the glucose absorption rate and that affects the normal postprandial plasma glucose level.

Lipase inhibitory function is the result of the prevention of the normal function of lipase by binding with the surface of the micelle substrates and affects the auto digestion of lipids (Wang and Huang, 1984; Gargouri *et. al.*, 1984).

2.3. LECTINS

Lectins were previously known as agglutinins or hemagglutinins, first discovered in plants but later also found in microorganisms and animals (Stillmark, 1888). These are a group of soluble heterogeneous glycoproteins that can easily attach to red blood cells and cause agglutination. Consumption of foods containing lectins may impair the transport and hydrolytic functions of enterocytes (Krupa, 2008). Though lectins are found in the highest concentration in seeds, other vegetative organs such as leaves, stems, barks, roots, and flowers may contain some amount. Lectins are resistant to digestion by pancreatic juice and like to bind with intestinal epithelial cells which causes damage to the intestinal tract and leads to impaired nutrient absorption (Muramoto, 2017). In a study, an independent mechanism is responsible for intestinal growth in rats by releasing CCK hormone and increasing the growth of the pancreas (Herzig *et. al.*, 1997). A strong relationship has been found between gut inflammation and joint inflammation and approximately 20% of patients with inflammatory intestinal disease (Crohn's disease) are complicated by joint inflammation (Hazenber *et. al.*, 1992). Lectins are heat resistant but can be destroyed by moist heating such as cooking because lectins are water soluble and typically found in the outer surface of a food, so water can expose them (Petrosski W. and Minich DM., 2020).

2.4. GOSSYPOL

It is a natural phenol which is a highly toxic substance for simple stomachs that can be found in the cotton seed derivatives. Gossypol can occur either in free form or gossypol protein complex. Rabbits

and pigs are more susceptible than poultry and ruminants. Ruminants are resistant to gossypol because of the formation of stable complexes with soluble protein in the rumen. The adverse effect of gossypol includes reduced hemoglobin content, cardiac irregularity, and accumulation of fluid in body cavities with a negative impact on certain liver enzymes (R. Ramchandra *et. al.*, 2019).

2.5. TANNINS

Tannins are a class of polyphenolic biomolecules weighing more than 500 Da. These are secondary compounds that are found in plant leaves, fruits, and bark which bind with precipitate protein and various organic compounds including amino acids and alkaloids. Joye (2019) has reported that tannin ingestion causes complex formation and reduces the activity of digestive enzymes which leads to protein indigestibility. Tannin not only forms complexes with proteins but also releases different types of toxic compounds into the stomach (Kumar, 1992). A high concentration of tannin lowers cellulose activity and affects the digestion of crude fibre which reduces the digestibility of dry matter and nutrients (R. Ramchandra *et. al.*, 2019). Tannin content can be reduced by both physiological and chemical processes. Tannin mostly accumulates in the seed coat, so by removing the bran can reduce its content. Tannin complexing agents, alkaline, formaldehyde, and organic acid solvents depress the bond of the tannin complex and lower the content.

2.6. SAPONINS

Saponins are non-volatile glycosides containing sugar in their structure. They are naturally produced as a foam-producing moiety of steroid or triterpenoid by many plant species including groundnut, lupin, lucerne, soybean, etc. (Kiranmayi, 2014). Saponins Have the property of interacting with monosaccharides and the cholesterol group of erythrocyte membranes which leads to hemolysis (Fleck *et. al.*, 2019). Previous studies have demonstrated that saponins depress the digestion and metabolism of nutrients. According to Ali *et. al.* (2006), saponins showed inhibitory activity of amylase enzyme. From the study of Cheeke (1971), it has been found that saponins can interfere with sterol activity and absorption by forming complexes with sterols and fat-soluble vitamins. A diet containing triterpenoid saponins reduces the absorption of vitamins A and E when fed to chicks (Jenkins and Atwal, 1994). Saponins can be degraded by the heat process, but rumen microbes sometimes degrade saponin in ruminants (R. Ramchandra *et. al.*, 2019).

2.7. GLUCOSINOLATES

Glucosinolates are sulfur-containing secondary metabolites of almost all plants of Brassica vegetables. They constitute a natural class of organic compounds that contain sulfur and nitrogen which are not toxic themselves, but their hydrolytic products are. Brassica plants contain the enzyme myrosinase which cleaves off the glucose group from glucosinolates and produces harmful products such as isothiocyanates and thiocyanates (T. Chun and B. Brian, 2004). Glucosinolates referred to as goitrogens and the products of hydrolysis of it with endogenous thioglucosidase are more harmful than the intact one (E. Underhill & D. Kirkland, 1980). These products from hydrolysis produce health hazards on different animals depending on the type and level present in the feed. Non-ruminant and young animals are more sensitive than ruminant and adult animals with health and production effects include depressed growth and production, reduced palatability and feed intake, hypothyroidism, and other disturbances (A. Achary and U. Thiyam, 2012). Pigs are more susceptible to being affected severely compared to other non-ruminants such as poultry and fish. According to (MK Tripathi and AS. Mishra, 2017) young ruminants can tolerate a total of $4.2\mu\text{mole g}^{-1}$ whereas pig 0.78, rabbits 7.0, poultry 5.4, and fish $3.6\mu\text{mole g}^{-1}$ diet. Different physical methods including steam heating, roasting, milling, microwave treatment, treatment with immersion water, etc. The simplest way is treatment with water (1:6) for 15-25 minutes can reduce glucosinolates by 98% and different solvents like ethanol, carbinol, acetone, and water decrease the lower molecular weight of glucosinolates (H. Fauduct *et. al.*, 1995). Drying improves the volatilization of isothiocyanates and the biological method usually fermentation by using microorganisms and enzymes reduces the toxicity of glucosinolates (Shcone F. *et. al.*, 1996).

3. EFFECTS OF ANFS ON HUMAN HEALTH

Antinutritional factors and toxic substances are present in food substances which limit the availability or function of nutrients. Vegetables and fresh food become a major concern because of the high level of antinutritional factors associated with health problems. According to (Soetan KO, 2008) antinutritional factors are generated naturally in plants but by different mechanisms, they work contrary to optimum nutrition. The presence of cyanogenic glycosides, protease inhibitors, lectins, tannins, alkaloids, and saponins in food may cause harmful effects like decreasing digestibility, increasing nitrogen content in feces, formation of kidney stones, allergic reactions, disturbance in mineral metabolisms, etc. (Habtamu Fekadu Gemedé & Negussie Ratta., 2014; Abhishek Thakur *et al.*, 2018). According to Cordain L. *et al.*, (2000), Some antinutritional factors have some positive impacts on immune modulation such as dietary lectin has an influence on both enterocyte and lymphocyte structure and function which reduces peripheral antigenic stimulation and reduction of disease symptoms in rheumatoid arthritis. Some research showed that using a low level of phytate, lectins, tannins, amylase inhibitors, and saponins helps to reduce blood glucose and insulin responses with the reduction of cancer risks (Habtamu Fekadu Gemedé & Negussie Ratta., 2014). Balancing the tolerance level of antinutritional factors with different kinds of processing and treatment is effective for animal and human health.

4. CONCLUSION

In most practical cases, the deleterious effects of anti-nutritional factors have been overlooked hindering the desired quality of nutritional factors present both in cereal grains and legumes. Present review forwarding the immense importance of eliminating the anti-nutritional factors through appropriate processes.

Disclaimer (Artificial Intelligent)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

REFERENCE

1. Aachary AA, Thiyam U. A pursuit of the functional nutritional and bioactive properties of canola proteins and peptides. *Crit Rev Food Sci Nutr.* 2012; 52: 965-979.
2. Ali, H., Houghton, P. J., & Soumyanath, A. α -Amylase inhibitory activity of some Malaysian plants used to treat diabetes; with particular reference to *Phyllanthus amarus*. *Journal of Ethnopharmacology.* 2006; 107(3): 449-455.
3. Bajpai, S., Sharma, A., & Gupta, M. N. Removal and recovery of antinutritional factors from soybean flour. *Food Chemistry.* 2005; 89(4): 497-501.
4. Berg-Lea, T., Brattås, L.-E., Krogdahl, A. Soybean proteinase inhibitors affect nutrient digestion in rainbow trout. In: Huisman, J., van der Pool, T.F.B., Liener, I. (Eds.), *Recent Advances of Research in Antinutritional Factors in Legume Seeds*. Pudoc, Wageningen. 1989; 22: 99-102.
5. Bhutkar, M. A., & Bhise, S. B. In vitro assay of alpha amylase inhibitory activity of some indigenous plants. *International Journal of Chemical Science.* 2012; 10: 457-462.
6. Caldwell, R.A. Effect of calcium and phytic acid on the activation of trypsinogen and the stability of trypsin. *J. Agric. Food Chem.* 1992; 40: 43-47.
7. Chan, S. S., Ferguson, E. L., Bailey, K., Fahmida, U., Harper, T. B., & Gibson, R. S. The concentrations of iron, calcium, zinc and phytate in cereals and legumes habitually consumed by infants living in East Lombok, Indonesia. *Journal of Food Composition and Analysis.* 2007; 20(7): 609-617.
8. Cheeke, P. R. Nutritional and physiological implications of saponins: A review. *Canadian Journal of Animal Science.* 1971; 51(3): 621-632.
9. Chun Chang T, Brian B. Isolation of intact Glucosinolates from Mustard seed meal to increase the sustainability of biodiesel utilization. *The Society for Engineering in Agricultural, food, and biological systems.* 2004; 046079.
10. Concon, J.M. Rapid method for the determination of lysine in cereal grains without hydrolysis. *Analytical biochemistry.* 1975; 66(2): 460-480.
11. Food and Agricultural Organization. *Groundnut: Post-harvest operations.* 2002; Rome: FAO.

12. Fauduct H, Coic JP, Lessire M. Rapeseed meal upgrading Pilot Scale Preparation of rapeseed meal materials with high or low glucosinolate contents. *Anim Feed Sci Technol.* 1995; 56(1–2): 99–109.
13. Fleck, J. D., Betti, A. H., Da Silva, F. P., Troian, E. A., Olivaro, C., Ferreira, F., & Verza, S. G. Saponins from *Quillaja saponaria* and *Quillaja brasiliensis*: Particular chemical characteristics and biological activities. *Molecules.* 2019; 24(1): 171.
14. Gargouri, Y., Julien, R., Pieroni, G., Verger, R., Sarda, L. Studies on the inhibition of pancreatic and microbial lipases by soybean proteins. *J. Lipid Res.* 1984; 25: 1214-1221.
15. Gupta, R. K., Gangoliya, S. S., & Singh, N. K. (2015). Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. *Journal of Food Science and Technology.* 2015; 52(2): 676–684.
16. Gu C, Pan H, Sun Z, Qin G. Effect of soybean variety on anti-nutritional factors content, and growth performance and nutrients metabolism in rat. *Int J Mol Sci.* 2010; 11(3): 1048-56.
17. Gulzar, M. Evaluation of weaning foods formulated from germinated wheat and mungbean from Bangladesh. *African journal of food science.* 2011; 5(17): 897-903.
18. Habtamu Fekadu Gemedo, Negussie Ratta. Antinutritional Factors in Plant Foods: Potential Health Benefits and Adverse Effects. *International Journal of Nutrition and Food Sciences.* 2014; 3(4): 284-289.
19. Handa, V., Kumar, V., Panghal, A., Suri, S., & Kaur J. Effect of soaking and germination on physicochemical and functional attributes of horsegram flour. *Journal of Food Science and Technology.* 2017; 54(13): 4229–4239.
20. Hazenberg MP, Klassen IS, Kool J, Ruseler-van Embden JG & Severijnen AJ. Are intestinal bacteria involved in the etiology of rheumatoid arthritis. *APMIS.* 1992; 100: 1–9.
21. Hossain, M.A., Jauncey, K. The effect of varying dietary phytic acid, calcium and magnesium levels on the nutrition of common carp, *Cyprinus carpio*. In: Kaushik, S.J., Luquent, P. (Eds) *Fish Nutrition in Practice. Proceedings of International Conference, Biarritz, France, 1992*; 705–715.
22. Herzig, K. H., Bardocz, S., Grant, G., Nustede, R., Fölsch, U. R., & Pusztai, A. Red kidney bean lectin is a potent cholecystokinin releasing stimulus in the rat inducing pancreatic growth. *Gut.* 1997; 41(3): 333–338.
23. Joye, I. Protein digestibility of cereal products. *Foods.* 2019; 8(6): 199.
24. Kiranmayi, P. Is bio active compounds in plants acts as anti nutritonal factors. *International Journal of Current Pharmaceutical Research.* 2014; 6(2): 36–38.
25. Kies, A. K., De Jonge, L. H., Kemme, P. A., & Jongbloed, A. W. Interaction between protein, phytate, and microbial phytase. In vitro studies. *Journal of Agricultural and Food Chemistry.* 2006; 54(5): 1753–1758.
26. Krupa, U. Main nutritional and antinutritional compounds of bean seeds-a review. *Polish Journal of Food and Nutrition Sciences.* 2008; 58(2): 149–155.
27. Kumar, R. Anti-nutritional factors, the potential risks of toxicity and methods to alleviate them. In *Legume trees and other fodder trees as protein source for livestock. FAO animal production and health paper.* 1992; 102: 145– 160.
28. Larsson, M., & Sandberg, A. S. Phytate reduction in oats during malting. *Journal of Food Science.* 1992; 57(4): 994–997.
29. Liener, I.E. Implications of antinutritional components in soybean foods. *J. Crit. Rev. Food Sci. Nutr.* 1994; 34: 31–67.
30. Liener, I. *Toxic Constituents of Plant Foodstuffs.* Academic Press, New York. 1980; 502: 7(1): 80-80.
31. Liu, K. Expanding soybean food utilization. *Food Technol.* 2000; 54: 46–58.
32. Liu, K. Chemistry and nutritional value of soybean components. In *Soybeans Boston: Springer.* 1997: 25–113.
33. Loren Cordain, L. Toohey, M. J. Smith and M. S. Hickey. Review article: Modulation of immune function by dietary lectins in rheumatoid arthritis, *British Journal of Nutrition.* 2000; 83: 207–217
34. Lott, J. N., Ockenden, I., Raboy, V., & Batten, G. D. Phytic acid and phosphorus in crop seeds and fruits: a global estimate. *Seed Science Research,*2000; 10(1): 11–33
35. Makkar, H. Antinutritional factors in foods for livestock. *BSAP Occasional Publication.* 1993; 16: 69-85.
36. Mattila, PH, Pihlava, JM, Hellström, J, Nurmi, M, Eurola, M, Mäkinen, S, Jalava, T and Pihlanto. Contents of phytochemicals and antinutritional factors in commercial protein-rich plant products. 2018; 2(4): 213-219.
37. Mejicanos G, Sanjayan N, Kim IH, et al. Recent advances in canola meal utilization in swine nutrition. *J Anim Sci Technol.* 2016; 58(1): 7.

38. Muramoto, K. Lectins as bioactive proteins in foods and feeds. *Food Science and Technology Research*. 2017; 23(4): 487–494.
39. Nadeem, M., Anjum, F. M., Amir, R. M., Khan, M. R., Hussain, S., & Javed, M. S. An overview of anti-nutritional factors in cereal grains with special reference to wheat-A review. *Pakistan Journal of Food Sciences*. 2010; 20(1–4): 54– 61.
40. Nørgaard *et al.* Exogenous xylanase or protease for pigs fed barley cultivars with high or low enzyme inhibitors. *Animal Feed Science and Technology*. 2018; 248: 10.
41. Okafor UI, Omemu AM, Obadina AO, Bankole MO, Adeyeye SA. Nutritional composition and antinutritional properties of maize ogi cofermented with pigeon pea. *Food science & nutrition*, 2018; 6(2): 424-39.
42. Patterson, C. A., Curran, J., & Der, T. Effect of processing on antinutrient compounds in pulses. *Cereal Chemistry*. 2017; 94(1): 2–10.
43. Petroski W, Minich DM. Is There Such a Thing as “Anti-Nutrients”? A Narrative Review of Perceived Problematic Plant Compounds. *Nutrients*. 2020; 12(10):2929.
44. Polak, R., Phillips, E. M., & Campbell, A. Legumes: Health benefits and culinary approaches to increase intake. *Clinical Diabetes* 2015; 33(4): 198–205.
45. Ramchandra Ramteke., et al. “Antinutritional Factors in Feed and Fodder used for Livestock and Poultry Feeding”. *Acta Scientific Nutritional Health*.2019; 3(5): 39-48.
46. Salas, C. E., Dittz, D., & Torres, M. J. Plant proteolytic enzymes: Their role as natural pharmacophores. In *Biotechnological applications of plant proteolytic enzymes*. 2018; 107–127.
47. Samtiya, M., Aluko, R.E. & Dhewa, T. Plant food anti-nutritional factors and their reduction strategies: an overview. *Food Prod Process and Nutr*. 2020; 2(6): 01-14.
48. Salunkhe H J, Barton P F and Kelly J A. “Polyphenols and Tannins in Cereals”, *Phytochemistry*. 1990; 38: 102- 105.
49. Schone F, Kirchheim V, Schumann W. Apparent digestibility of high fat rapeseed press cake in growing pigs and effects on feed intake, growth and weight of thyroid and liver. *Anim Feed Sci Technol*. 1996; 62(2– 4): 97–110.
50. Soetan KO. Pharmacological and other beneficial effects of anti-nutritional factors in plants-A Review. *Afr. J Biotechnol*. 2008; 7(25): 4713- 4721.
51. Srinivasan B. "A guide to enzyme kinetics in early drug discovery". *The FEBS Journal*. 2022; 290 (9): 2292-2305.
52. Stalker, H. T. (Peanut (*Arachis hypogaea* L.). *Field Crops Research*. 1997; 53(1–3): 205–217.
53. Sun, Z.W.; Qin, G.X. Soybean antigens and its influence on piglets and calves. *Acta Zoonutrim. Sinica*. 2005; 17: 20–24.
54. Temba, M. C., Njobeh, P. B., Adebo, O. A., Olugbile, A. O., & Kayitesi, E. The role of compositing cereals with legumes to alleviate protein energy malnutrition in Africa. *International Journal of Food Science & Technology*. 2016; 51(3): 543–554.
55. Thanaseelaan V. Proximate Analysis, Mineral and amino acid profiles of De-oiled rapeseed meal. *International Journal of Food, Agriculture and Veterinary Sciences*. 2013; 3(1): 66–69.
56. Tharanathan, R. and S. Mahadevamma. Grain legumes—a boon to human nutrition. *Trends in Food Science & Technology*. 2003; 14(12): 507-518.
57. Tripathi MK, Mishra AS. Prospects and Problems of Dietary Glucosinolates in Animal Feeding. *J Adv Dairy Res*. 2017; 5(3): 180.
58. Underhill E, Kirkland D. (1980). Glucosinolates in secondary plant products. In: Bell EA, Charlwood BV, editors. *Encyclopedia of plant physiology, New series*. Berlin: Springer-Verlag. 1980: 493–511.
59. Vadivel, V., Kunyanga, C. and Biesalski, H. Health Benefits of Nut Consumption with Special Reference to Body Weight Control. *Nutrition*. 2012; 28: 1089-1097.
60. Wang, S.M., Huang, A.H.C. Inhibitors of lipase activities in soybean and other oil seeds. *Plant Physiol*. 1984; 14: 263-271.
61. Mamoudou S, Habiba K. Entomotoxic Effect of Five Varieties of Bambara Groundnut (*Vigna subterranea*) and a Variety of Red Bean (*Phaseolus vulgaris*) against Old Larvae and Adults of *Tribolium castaneum* Herbst (Coleoptera, Tenebrionidae). *J. Exp. Agric. Int.* [Internet]. 2024 Jan. 31 [cited 2024 Jun. 2];46(2):9-22. Available from: <https://journaljeai.com/index.php/JEAI/article/view/2304>

62. Singh B, Pavithran N, Rajput R. Review- Effects of Food Processing on Nutrients. Curr. J. Appl. Sci. Technol. [Internet]. 2023 Dec. 2 [cited 2024 Jun. 2];42(46):34-49. Available from: <https://journalcjast.com/index.php/CJAST/article/view/4292>
63. Samtiya M, Aluko RE, Dhewa T. Plant food anti-nutritional factors and their reduction strategies: an overview. Food Production, Processing and Nutrition. 2020 Dec;2:1-4.

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